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SUMMARY OF PERFORMANCE TESTS OF TWO
SIDE INLET, STEAM-TO-AIR JET PUMPS

by A.M. Heinrich

Engineering Report No. 146

for the Office of Naval Research
Contract N-onr 201(01)



June 1954
University of Wichita
School of Engineering
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SUMMARY OF PERFORMANCE TESTS OF TWO SIDE INLET, STEAM-TO-AIR JET PUMPS

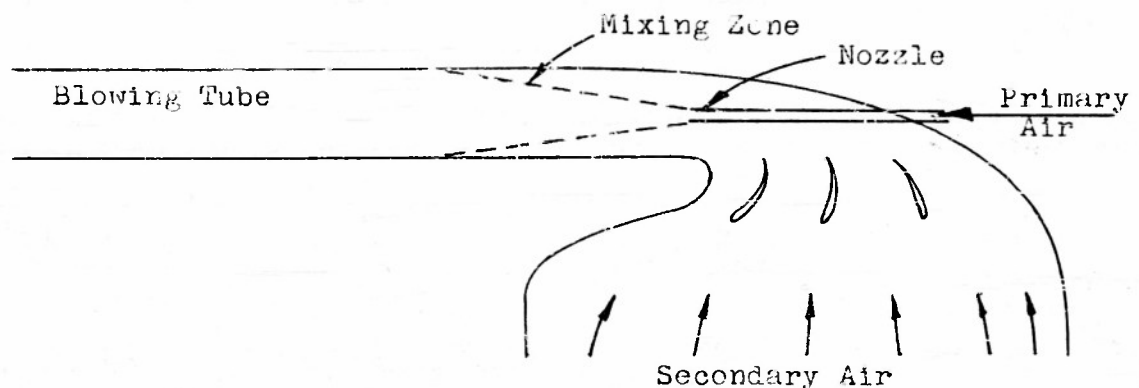
SUMMARY

Two types of side-inlet, jet-pump mixing tubes, cylindrical and tapered, have been tested to determine their operating characteristics. The pumps were tested under various conditions of pressure ratio, primary total pressure, secondary flow guidance at the side-inlet, and suction slot air-flow distribution.

The results of these tests showed the relative importance of factors most influential in the performance of the side-inlet jet pump. In general the tapered mixing tube was superior to the cylindrical mixing tube, since it produced better flow distribution, higher pressure ratios, and larger mass ratios.

INTRODUCTION

Generally the jet-pump takes the form of a central jet discharging axially into a tapered or cylindrical mixing tube. The secondary air is drawn in around the discharging jet, is entrained by the jet, and the ensuing mixture is ejected from the downstream end of the mixing tube. Such a configuration, because of its geometry, is not easily used as the pumping unit for a suction-blowing system of airplane wing circulation control. The secondary air that is drawn in immediately forward of a suction flap, must be converged to the inlet shape of the mixing tube. If the mixing tube is placed in the airplane with its axis spanwise, as is usually the case, the secondary air suffers large turning losses. Also, the unequal distances from the slot to mixing tube entrance causes unequal distribution of duct losses with subsequent unequal slot flow distribution. Choking devices in the slot or duct are then required to give slot air-flow distribution and are accompanied by additional losses. The following sketch is a typical installation-



As a developmental step toward the particular application of a jet pump into a wing circulation-control system, it was conceived that distributed suction along the mixing tube would eliminate several of the above-mentioned loss factors. This was contingent on obtaining satisfactory pump efficiency and suction-slot flow distribution.

A short transmission duct of constant chordwise length was used to connect the mixing tube and the constant-width suction slot. The secondary air was turned through a maximum of 90 degrees in the side inlet of the mixing tube. This arrangement is depicted by figures 1 and 2 for the cylindrical and tapered mixing tubes.

A side-inlet steam-to-air jet pump with an inboard nozzle based upon the above described configuration was the subject of this investigation. Tests were performed to determine comparative performance characteristics with various operating conditions.

This report is a summary of the test data presented in two previous reports, references 2 and 3. The design, construction and tests of the jet pumps were performed by the University of Wichita, School of Engineering under the authority of Contract N-onr 201(01) from the Air Branch of the Office of Naval Research.

SYMBOLS

D	diameter of mixing tube or orifice, inches
ρ	mass, slugs/ft ³
q	dynamic pressure, lbs/ft ²
Q	volumetric flow rate, ft ³ /sec
P	power, ft-lb/sec
p_t	total pressure, lbs/ft ²
V	velocity, ft/sec
w	weight flow rate, lbs/sec
α	pressure ratio = p_{t3}/p_{t0}
μ	mass ratio = w_s/w_j
γ	efficiency = P_{eff}/P_{in}

Subscripts

0	free stream or ambient condition
1	suction slot condition
2	mixing-tube-entrance throat condition
3	mixing-tube exit condition
AE	available energy
j	primary or jet flow

4

s secondary flow
 m mixture of primary and secondary flow
 x axial position from the inboard end of mixing tube
 in input
 eff effective

APPARATUS, TESTS, AND PERFORMANCE ANALYSIS

Tests of the jet-pump mixing tubes were fully described in references 2 and 3. The two, side-inlet jet pumps tested are shown in figures 1 through 4.

The jet-pump performance parameters, detailed in references 1 and 2, are presented in summary below:

The approximate total-pressure losses in the suction duct were determined from the relation

$$\begin{aligned}\Delta p_t &= p_{t1} - p_{t2} = p_{t0} - \left[(p_{t0} + p_2) + \frac{1}{2} \rho_2 V_2^2 \right] \\ &= -p_2 - \frac{1}{2} \rho_2 V_2^2.\end{aligned}$$

These losses were reduced to a dimensionless value for comparative purposes as the ratio of the total-pressure loss to the average, throat dynamic pressure, $\frac{\Delta p_t}{q_2}$.

The efficiency was determined from the ratio of effective power output to power input

$$\eta = \frac{P_{eff}}{P_{in}} = \frac{Q_s(p_{t3} - p_{t1}) + Q_j(p_{t3} - p_{t0})}{w_j \Delta h_j}.$$

The mass ratio was expressed by the weight-flow ratio

$$\mu = \frac{w_s}{w_j}.$$

Jet-pump pressure ratio was defined as the ratio

$$\alpha = \frac{p_{t3}}{p_{t0}}.$$

The available energy efficiency at any point in the mixing tube was the ratio of the local available energy of the mixture to the available energy of the primary flow at the

nozzle and was expressed by the relation of kinetic and pressure energies,

$$\eta_{AE_x} = \frac{\frac{1}{2} \rho_{m_x} v_{m_x}^2 + p_{m_x}}{\frac{1}{2} \rho_j v_j^2}$$

DISCUSSION

Figures 5 through 7 show the comparative performance on the cylindrical and tapered mixing tubes. The performance of the tapered mixing tube is shown both with and without control of the suction-slot air-flow distribution. The performance peak for the tapered mixing tube with air-flow distribution was governed by the maximum throat opening size of the model. By properly matching the throat area with the pressure ratio this performance peak should approach that without flow distribution, since the peak was caused by the increased throttling losses required for distribution.

Figure 8 shows the comparison of available-energy distribution between the cylindrical and tapered mixing tubes. Ideally, available energy should exist as far along the mixing tube as the secondary flow side inlet.

The suction-duct losses for the two mixing tubes are shown in figure 9. The increase of pressure loss as the secondary flow became less was a result of flow discontinuities in the suction duct. These discontinuities in the form of turbulence, reverse flow, cross flow, and vortices produced losses which reduced the amount of pumped secondary quantity. The losses for the tapered-mixing-tube inlet with smooth flow were small and consisted primarily of the inlet and frictional losses in the suction duct.

Figures 10 and 11 show the effect of mixing-tube shape on the optimum suction-slot, air-flow distribution and the slot-width variation that was required to obtain the desired distribution. The accompanying effects of the mixing tube shape on the throat static pressure distribution is shown in figure 12. Figure 13 shows the two mixing-tubes throat widths that produced the distribution of secondary air-flow shown in figure 10.

The mixing tube static pressure distributions are shown in figure 14. The curve for the cylindrical mixing tube shows that the pumping power existed primarily in

the inboard area while the tapered mixing tube had pumping power distributed throughout the length of the mixing tube. The peak of the static pressure for the tapered mixing tube was a result of high local losses in the entrance throat configuration required for slot air-flow distribution. Ideally, this static pressure distribution should be constant throughout the mixing tube to have the most efficient mixing and the most satisfactory suction-slot flow.

Figure 15 shows the total pressure profiles of the mixing flow at the end of the mixing tube. In both the cylindrical and tapered mixing tubes the flow was mixed in this region.

CONCLUSIONS

The experimental analysis of two side-inlet, steam-to-air jet pumps has provided data for a comparative evaluation. This evaluation showed that the pump with a tapered mixing tube had a much superior performance to the pump with a cylindrical mixing tube. The tapered mixing tube gave better control of the primary jet diffusion which resulted in improved pumping efficiency at higher pressure ratios and in easier control of the suction-slot air flow distribution.

For specific design of a side-inlet jet pump with an inboard nozzle the following influential factors were found important to improved performance.

1. Constant static pressure along the side-inlet mixing tube.
2. Constant slot width.
3. Constant throat width.
4. Constant area suction duct.
5. Cascade for turning the air into the side-inlet mixing tube.

REFERENCES

- 1.- Heinrich, A.M.: Pre-test Report on the Performance Study of a Side-Inlet Jet-Pump with an Inboard Nozzle. University of Wichita Engineering Study No. 117, October 1953.
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- 3.- Heinrich, A.M.: Performance Test of a Side-Inlet, Steam-to-Air Jet Pump with an Inboard Nozzle and a Tapered Mixing Tube. University of Wichita Engineering Report No. 138, May 1954.

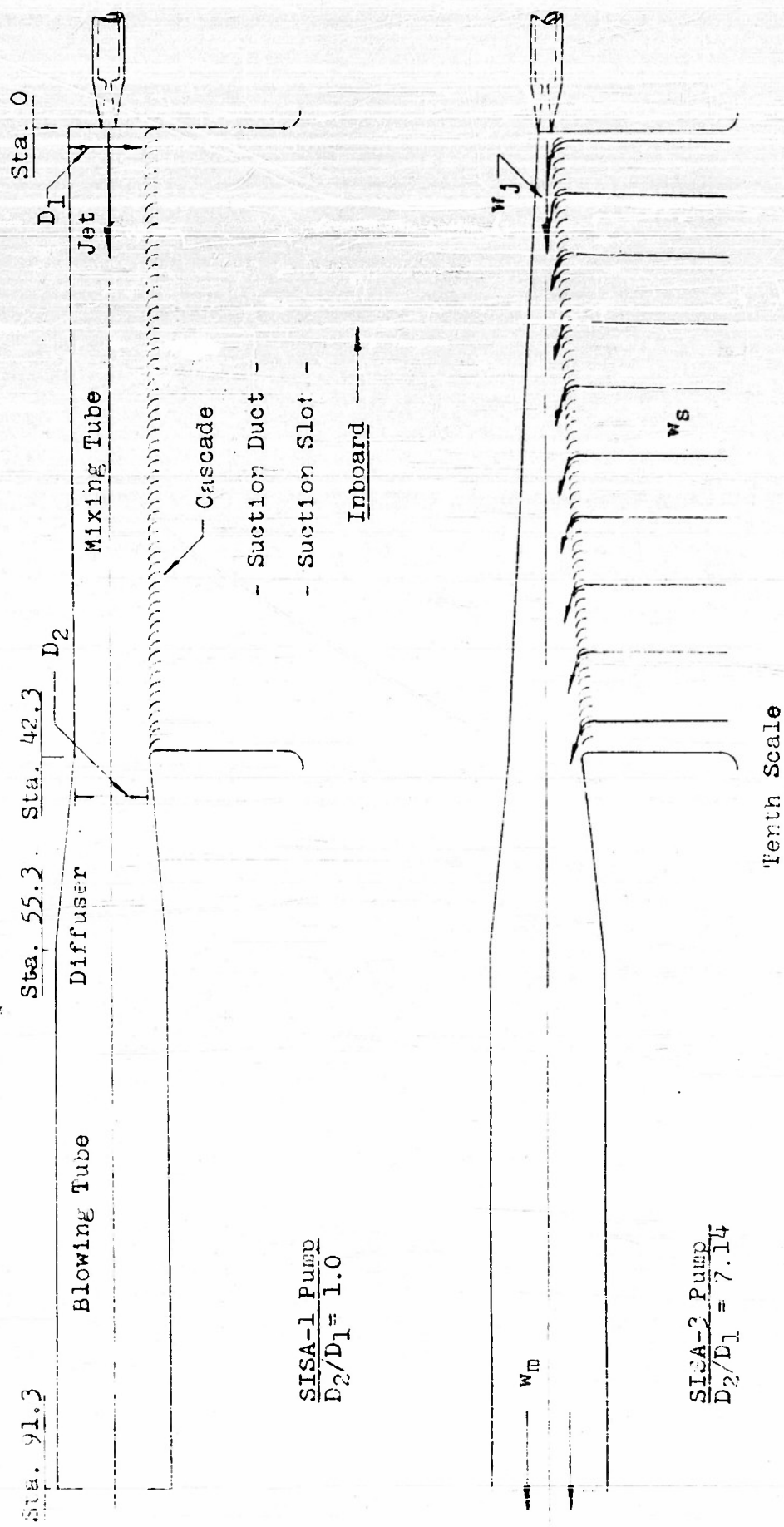


Figure 1.- Planform outline, side inlet, steam-to-air jet-pump

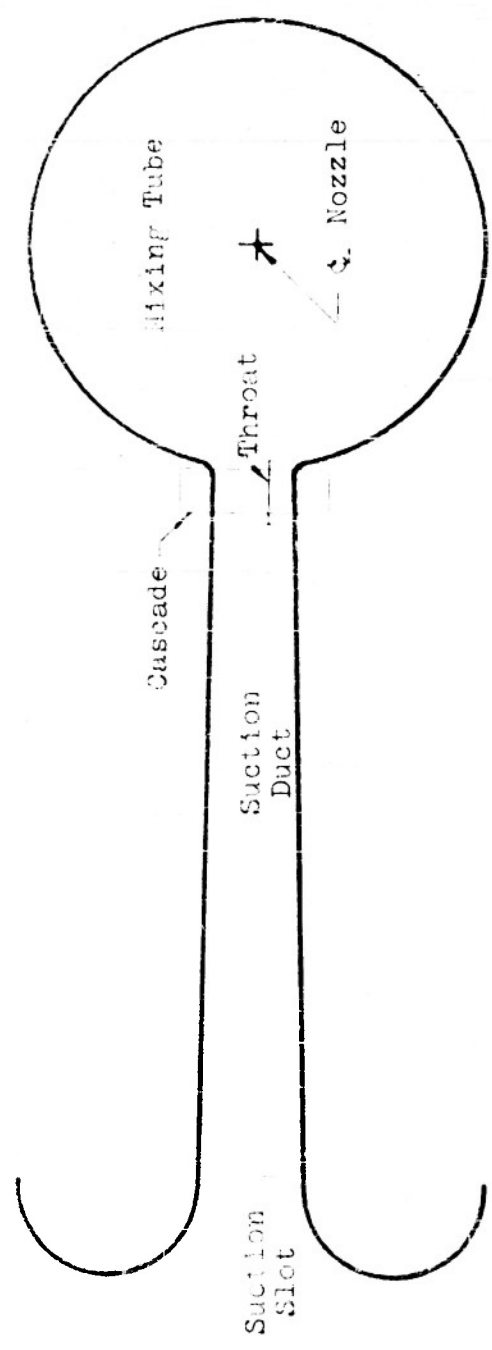


Figure 2.- Cross Section of Side-Inlet, Steam-to-Air Jet Pump

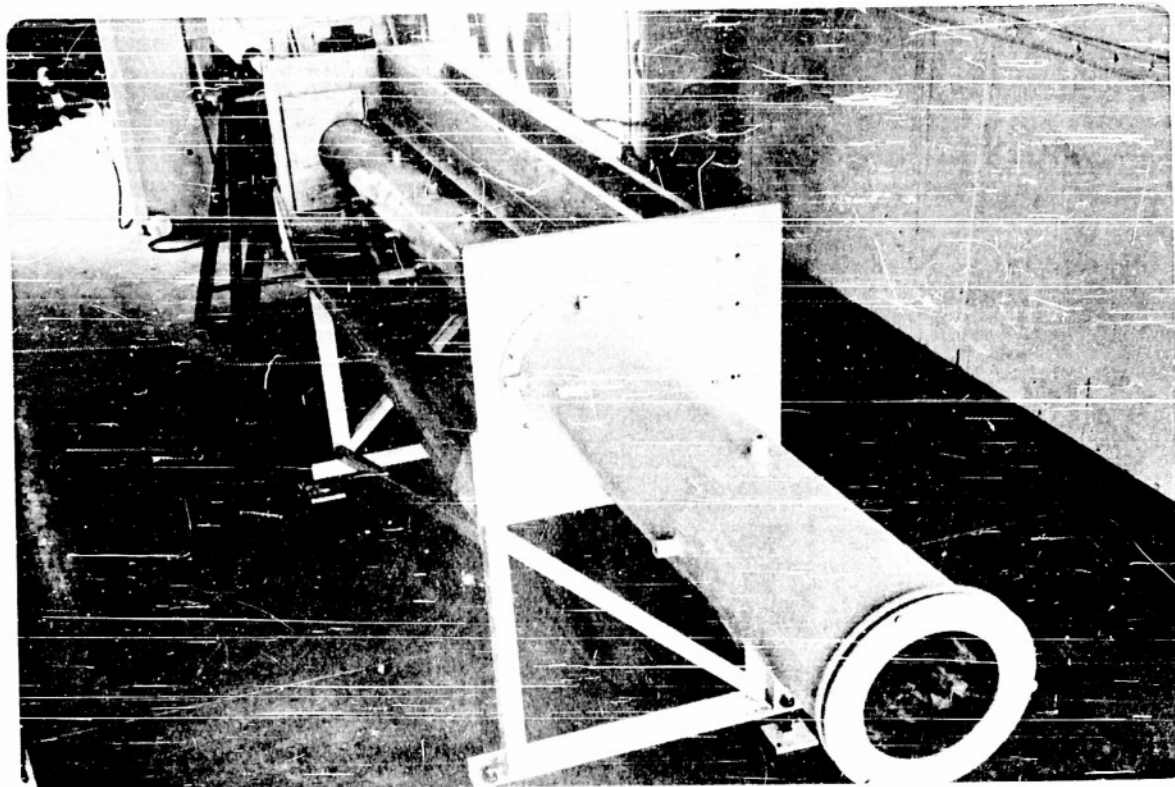


Figure 3. Side-inlet jet pump with cylindrical mixing tube.

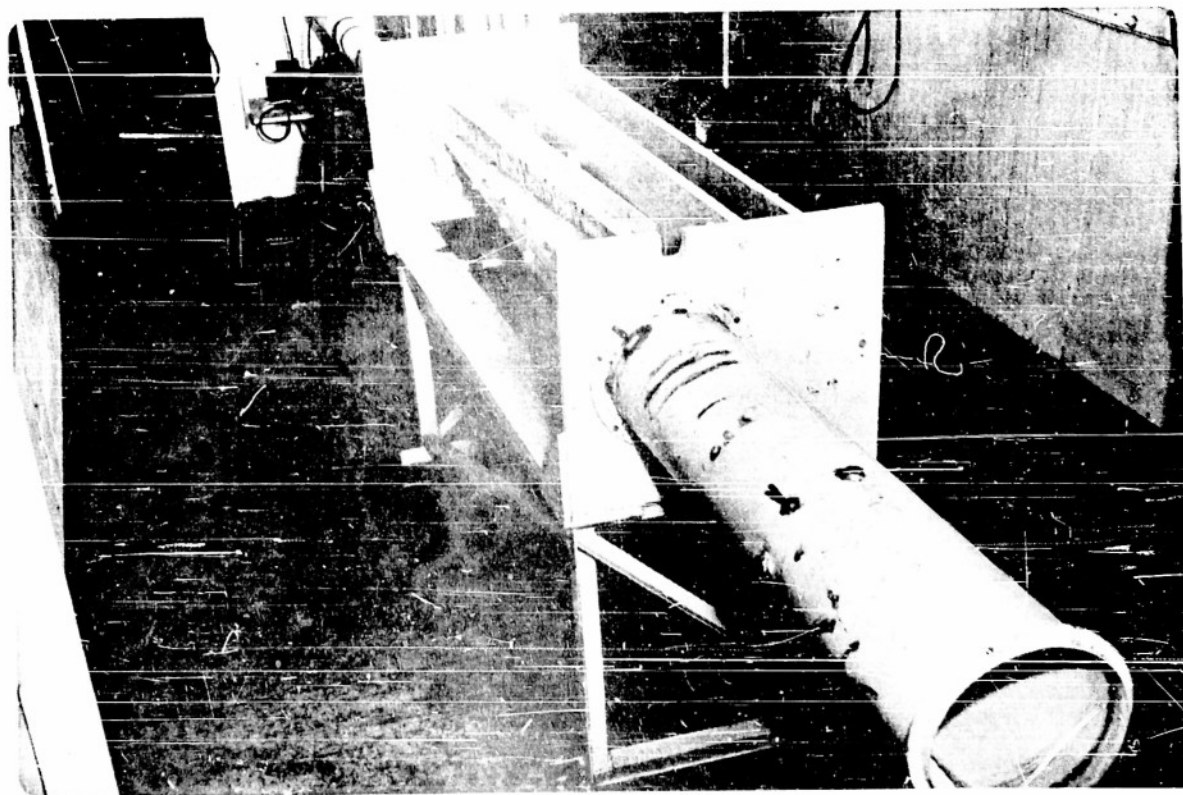
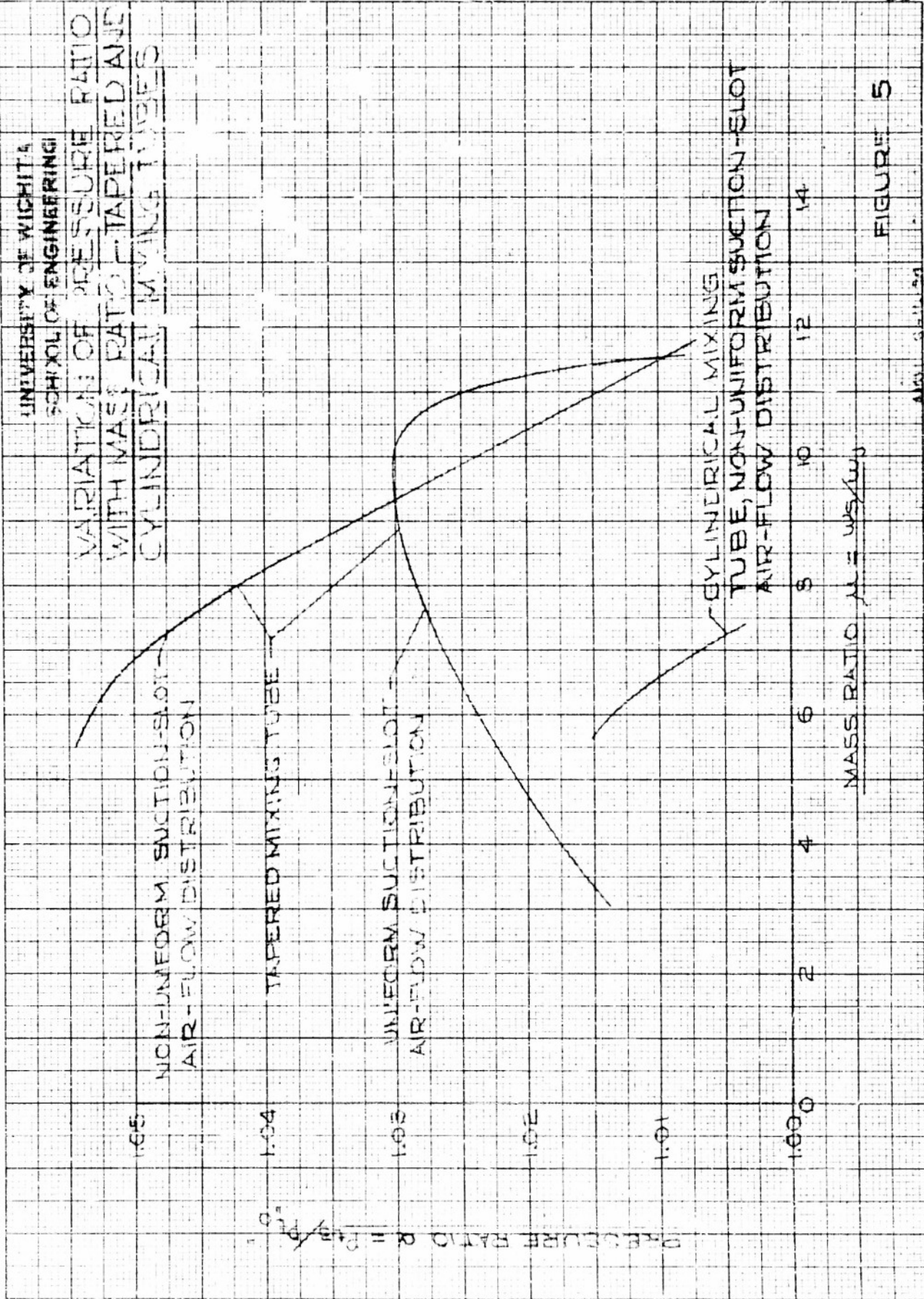


Figure 4. Side-inlet jet pump with tapered mixing tube.



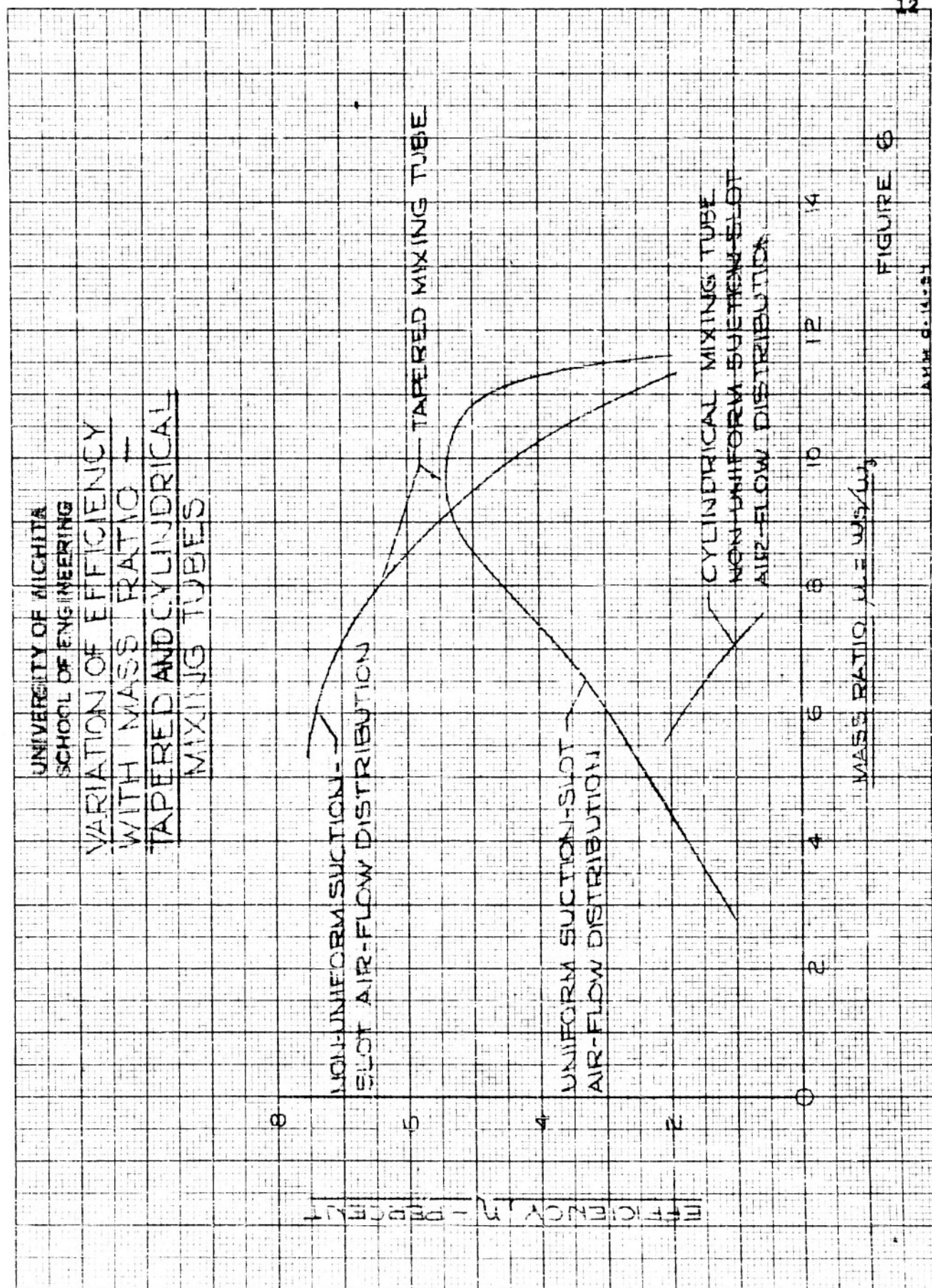
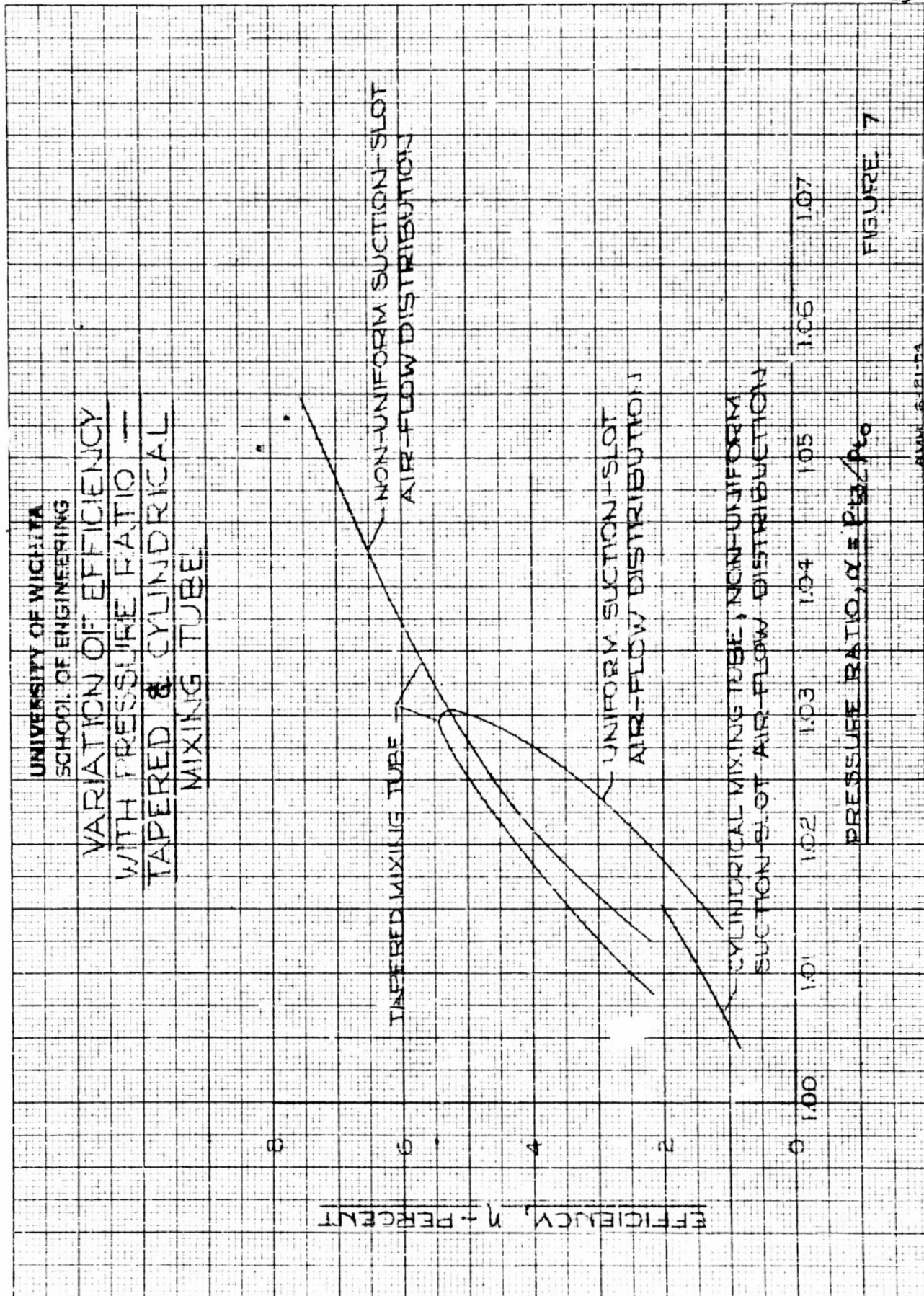


FIGURE 6



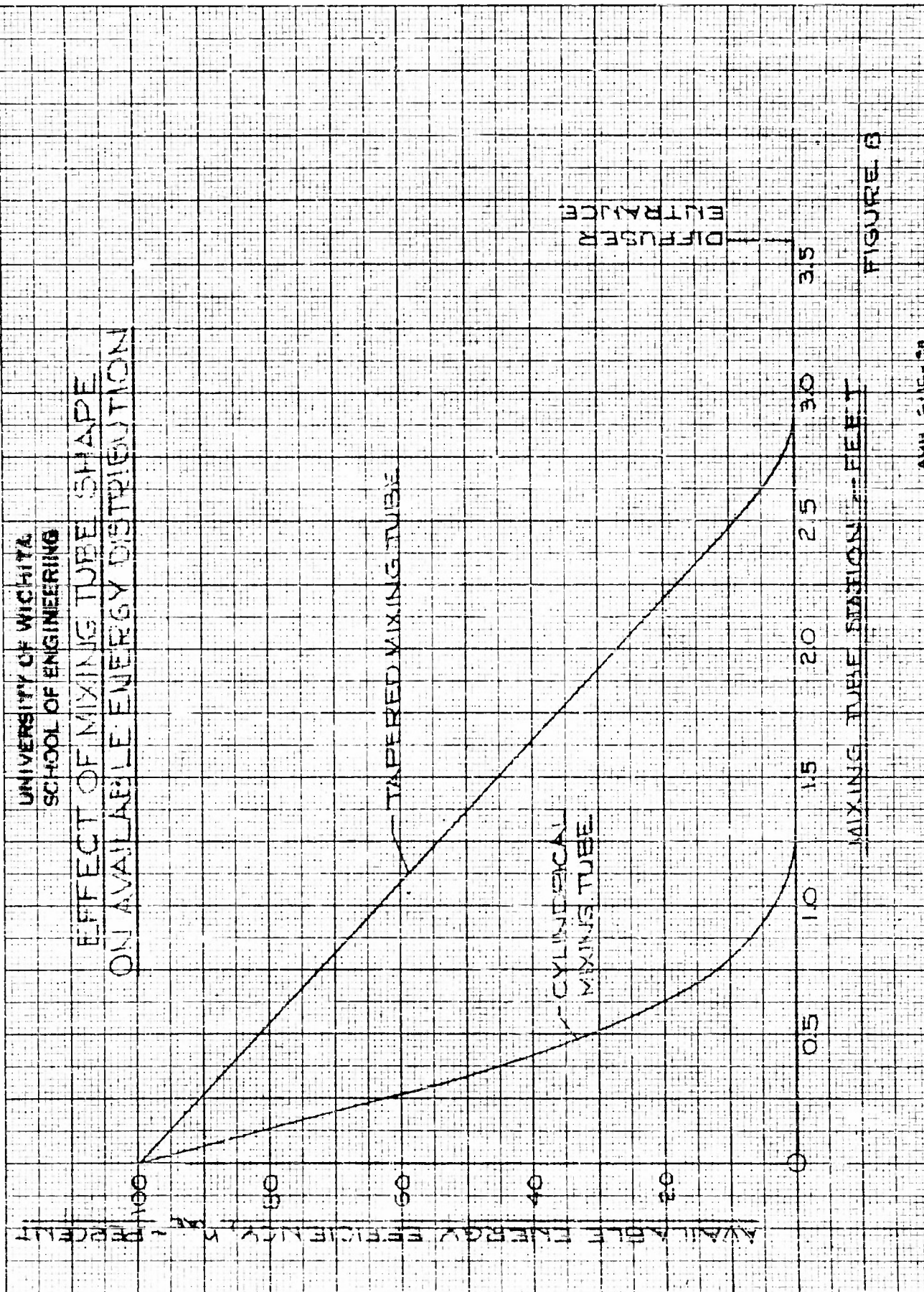


FIGURE 6

SUCTION DUCT LOSS FOR THE TAPERED & CYLINDRICAL MIXING TUBES

$w_j = \text{CONSTANT}$

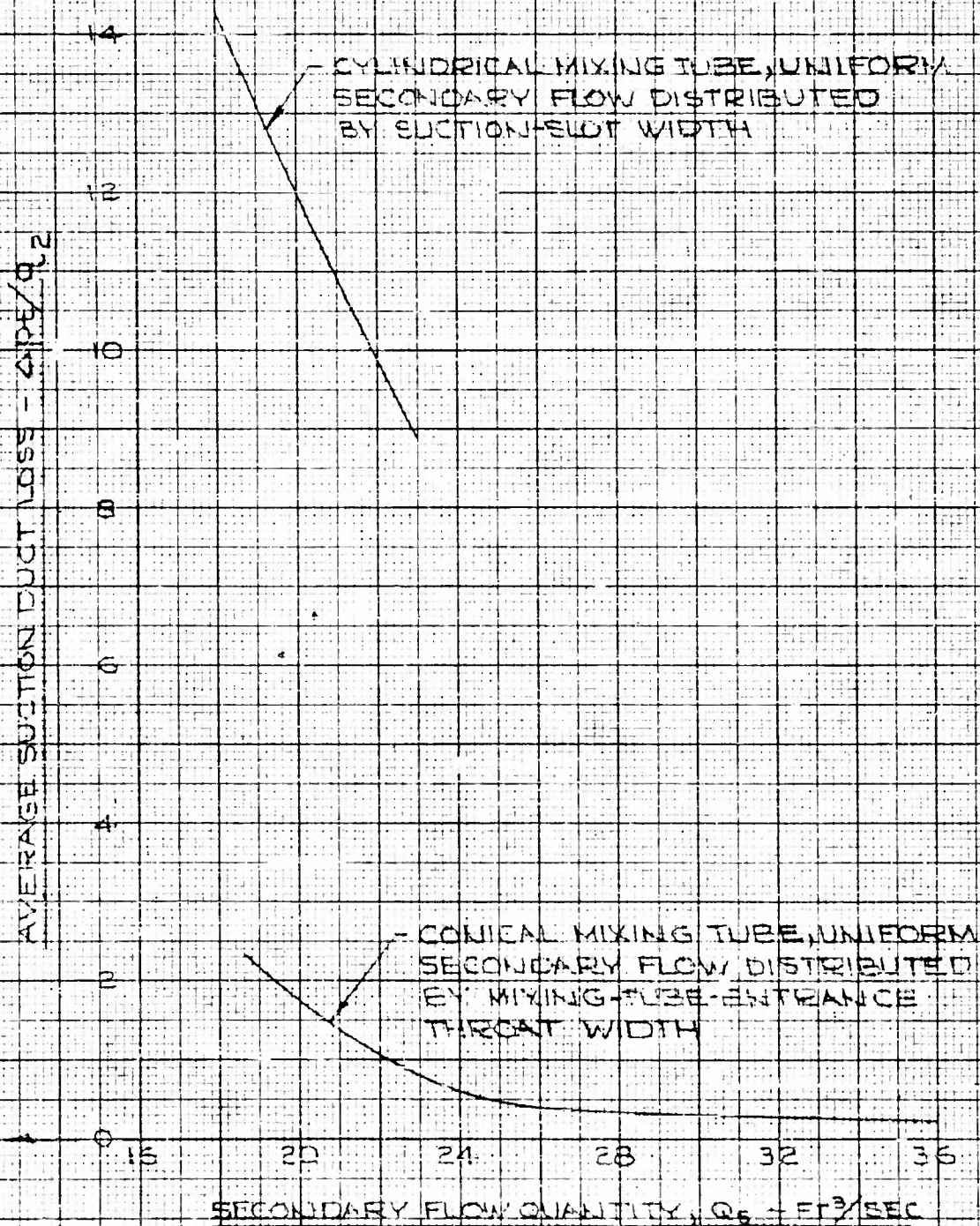
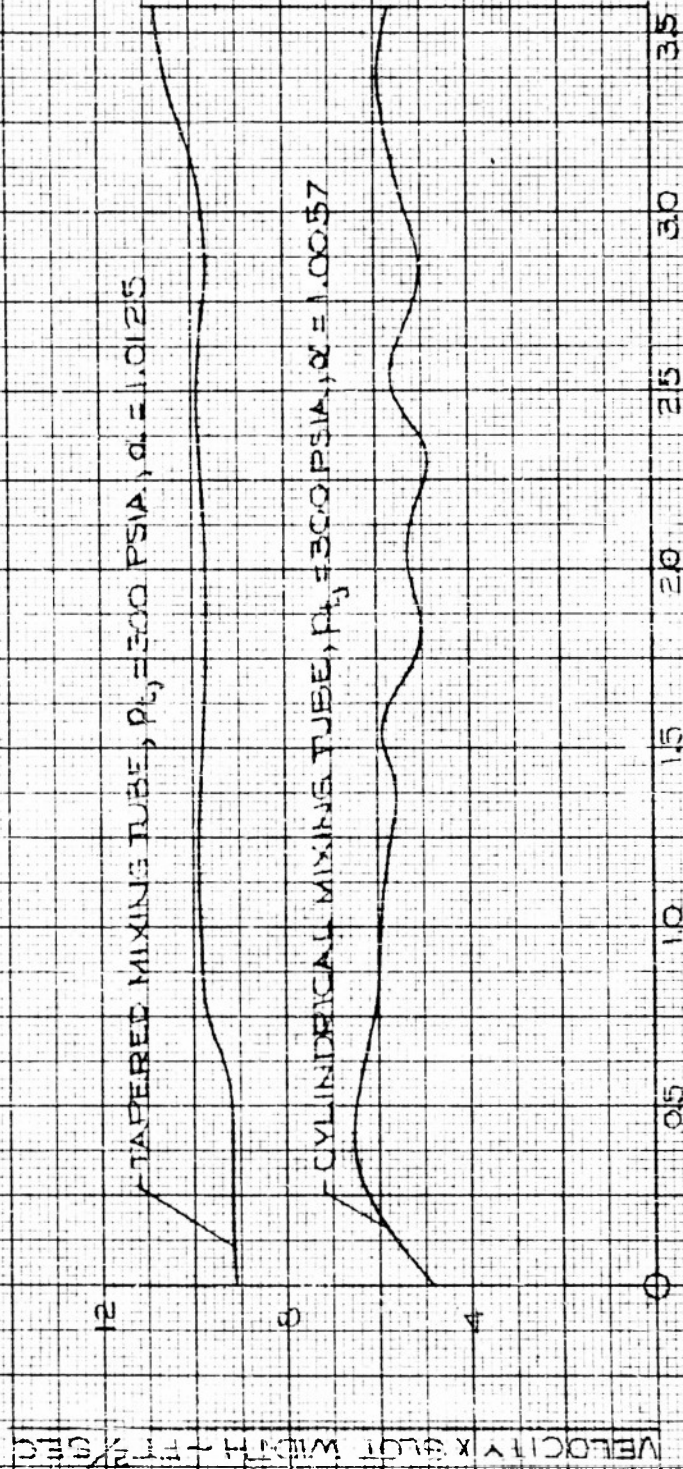


FIGURE 9

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EFFECT OF MIXING TUBE SHAPE ON
 THE OPTIMUM SUCTION SLOT QUANTITY DISTRIBUTION



SUCTION SLOT STATION - FEET

FIGURE 10

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 EFFECT OF MIXING TUBE SHAPE ON
 THE SUCTION SLOT WIDTH WITH
 OPTIMUM FLOW DISTRIBUTION



FIGURE 11

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EFFECT OF MIXING TUBE SHAPE ON
 THROAT STATIC PRESSURE DISTRIBUTION
 WITH OPTIMUM FLOW DISTRIBUTION

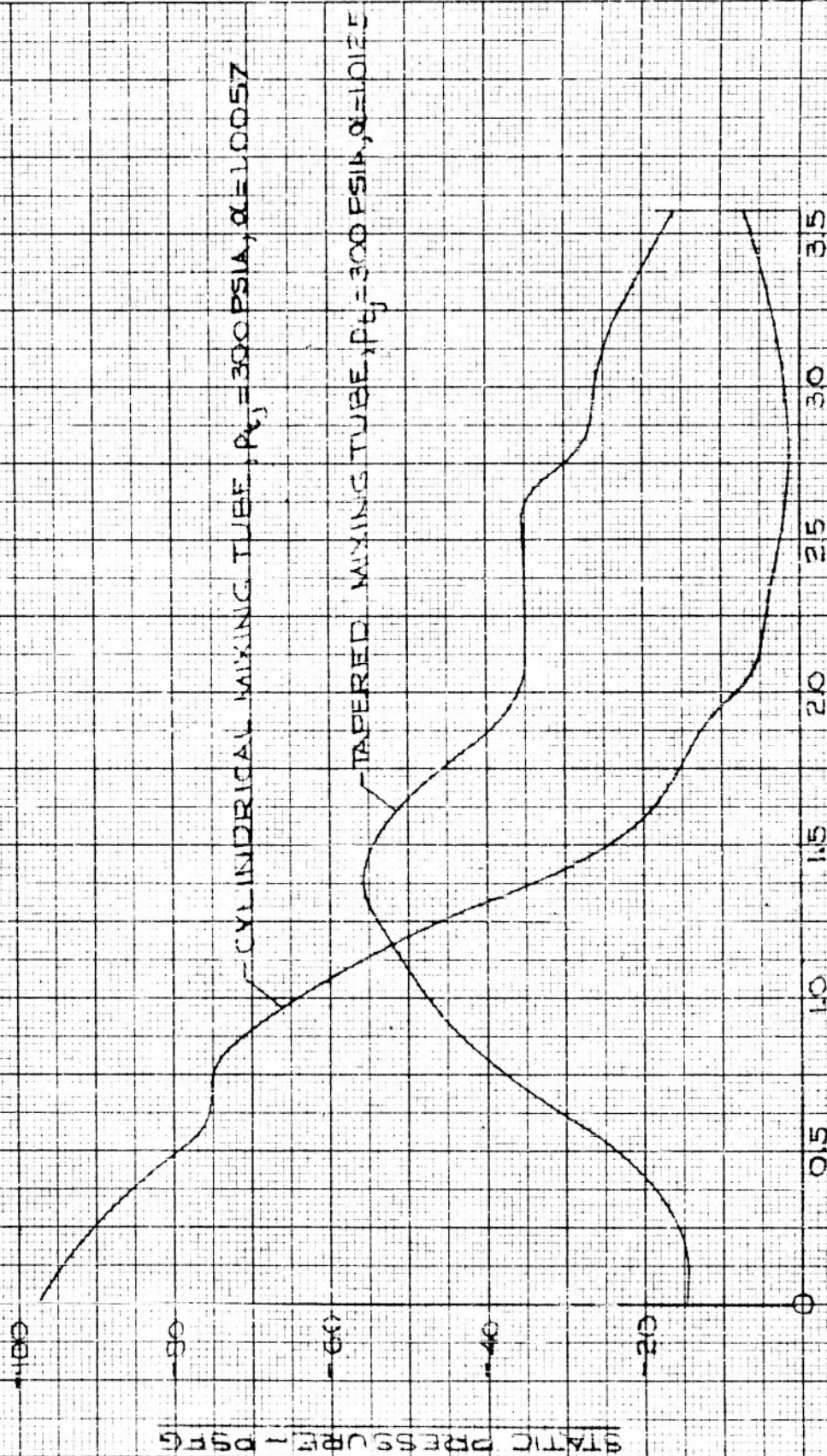


FIGURE 12

THROAT STATION - FEET

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EFFECT OF MIXING TUBE SHAPE ON THE THROAT WIDTH WITH OPTIMUM SLOT FLOW DISTRIBUTION

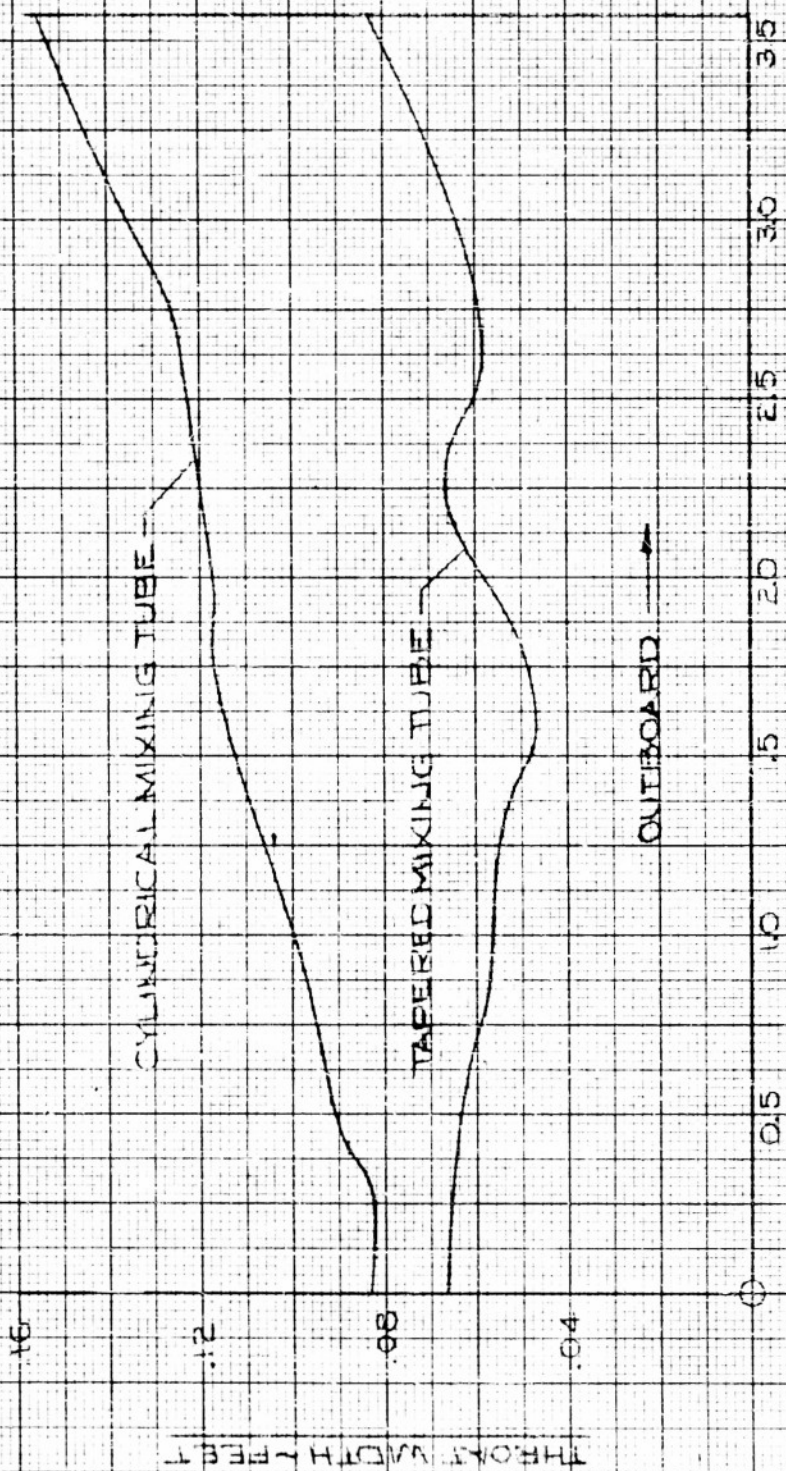


FIGURE 13

UNIVERSITY OF MICHIGAN
SCHOOL OF ENGINEERING

EFFECT OF MIXING TUBE SHAPE ON
MIXING TUBE STATIC PRESSURE WITH
OPTIMUM SLOT FLOW DISTRIBUTION

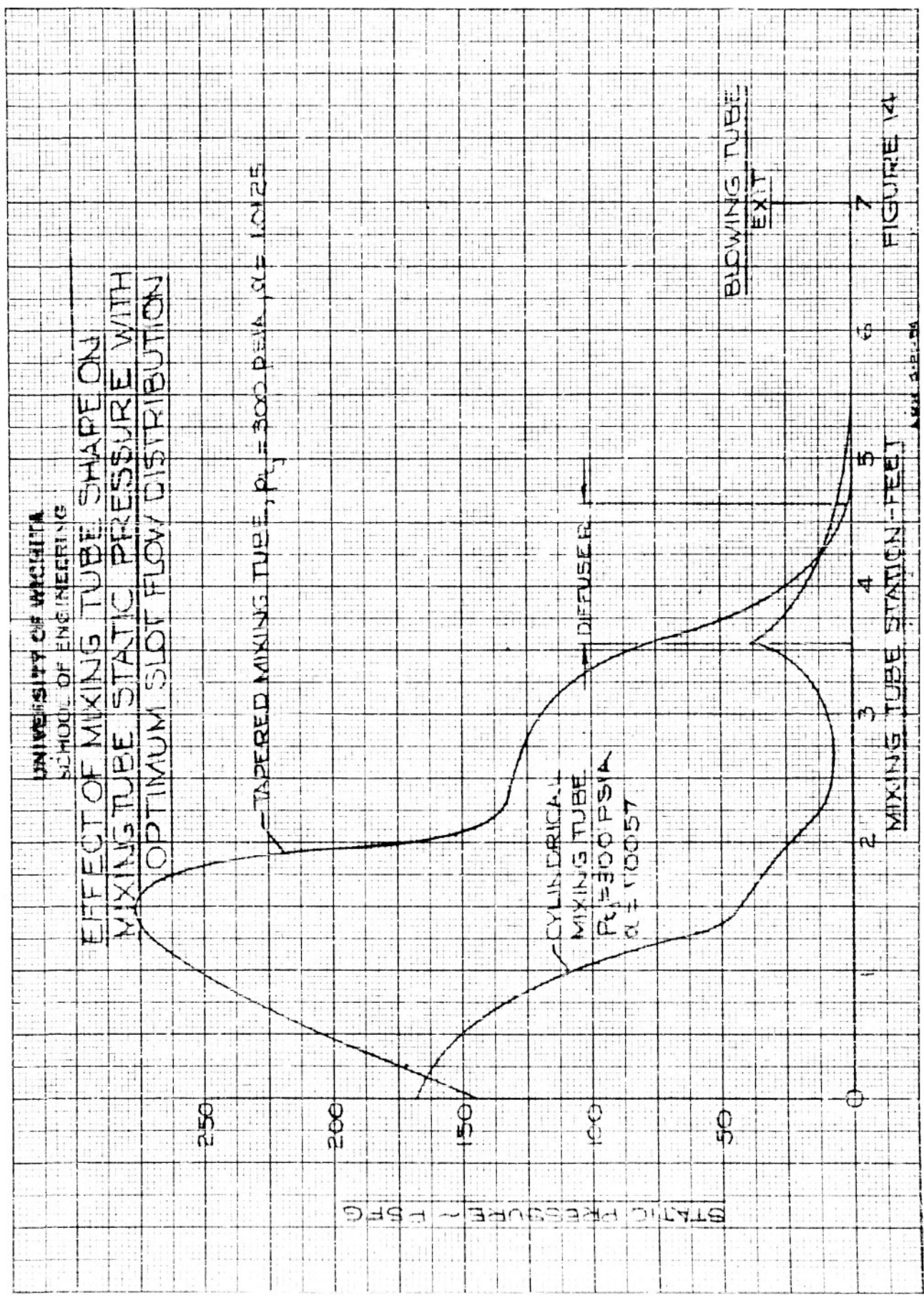
TAPERED MIXING TUBE, $P_1 = 300$ PSIA, $\alpha = 1.0125$

CYLINDRICAL
MIXING TUBE
 $P_1 = 300$ PSIA
 $\alpha = 1.0057$

DIFFUSER

BLOWING TUBE
EXIT

FIGURE 14



UNIVERSITY OF ALABAMA
 SCHOOL OF ENGINEERING
 EFFECT OF MIXING-TUBE SHAPE ON
 TOTAL PRESSURE

— HORIZONTAL DISTRIBUTION
 ---- VERTICAL DISTRIBUTION

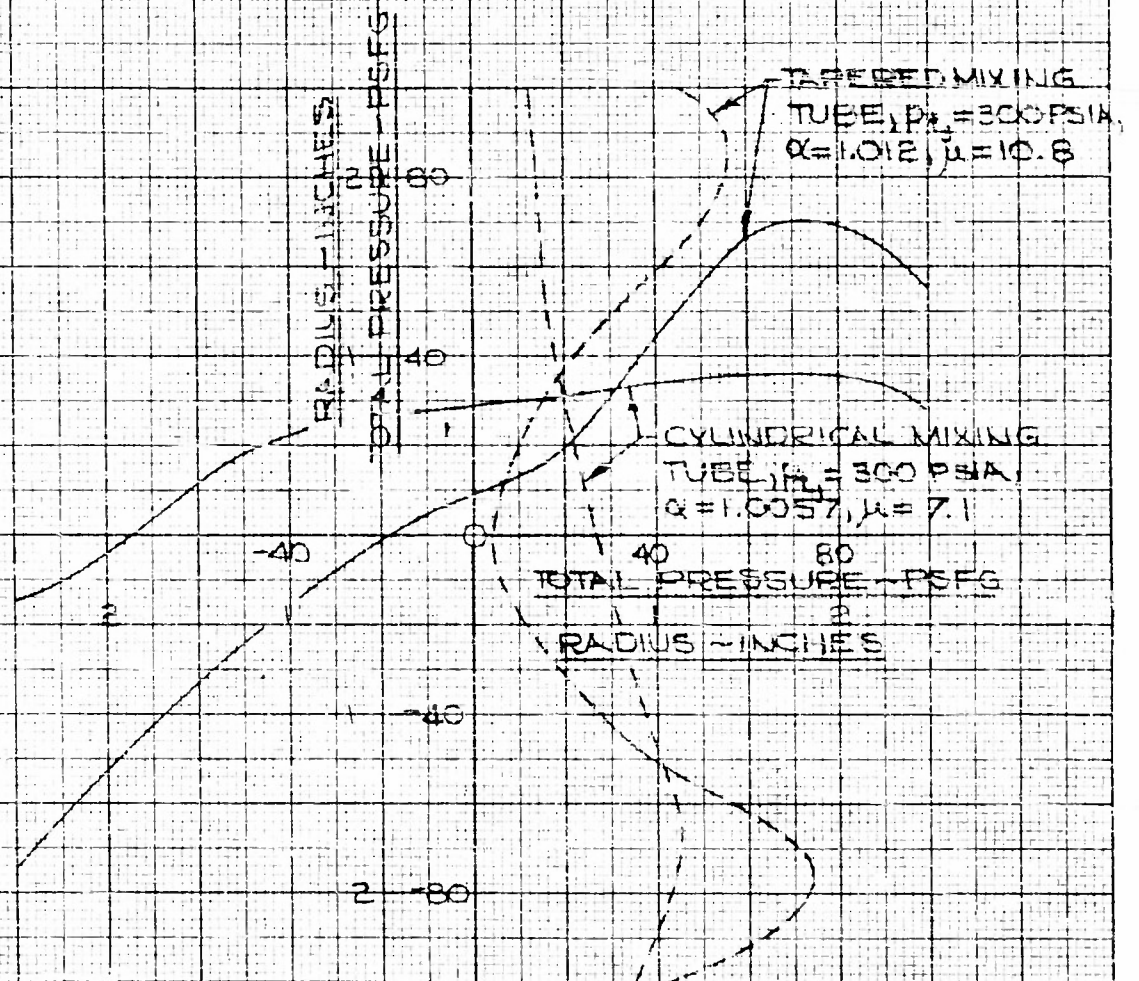


FIGURE 15

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2.- Jet Pumps
I.- Heinrich, A.M.
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